

Tau neutrino appearance with ORCA

Status and Prospects

ORCA after the Letter of Intent

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MANTs Meeting 2016 in Mainz



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Status of new ORCA simulations with real detector geometry



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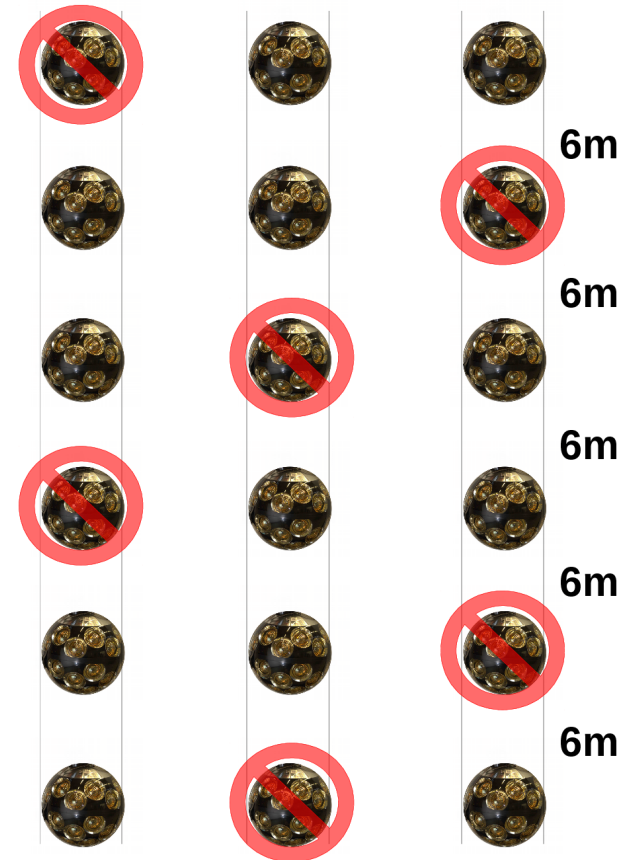
ORCA simulation up to now



Standard simulation used in Letter of Intent for KM3NeT 2.0

[*J. Phys. G*, 43 (8), 084001, 2016 (*arXiv:1601.07459*)]

- digital optical modules (DOMs)
housing 31 3" PMTs each
- 18 DOMs per string
- 115 strings
- ~ 20 m average horizontal spacing
- 6 m vertical spacing
→ **effective 9 m spacing:**
Masking + rescaling ($\times 1.5$) of effective volume



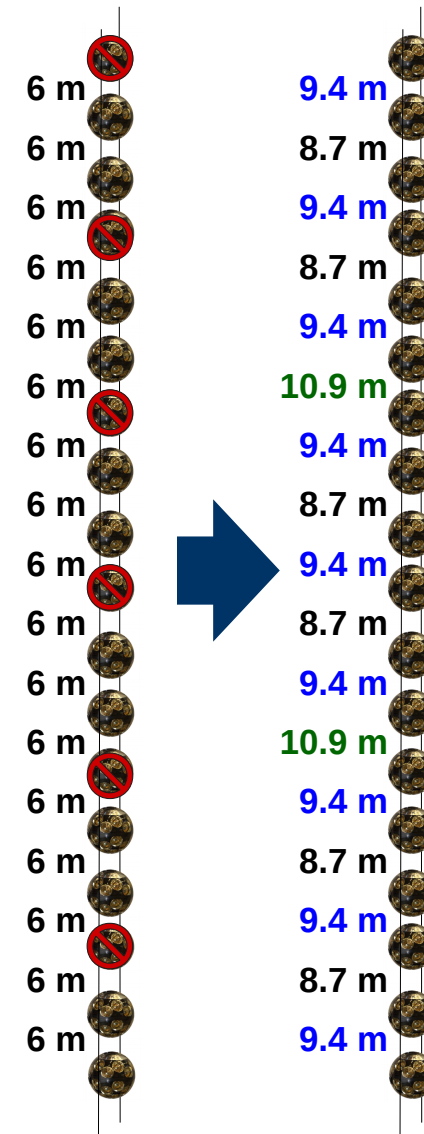
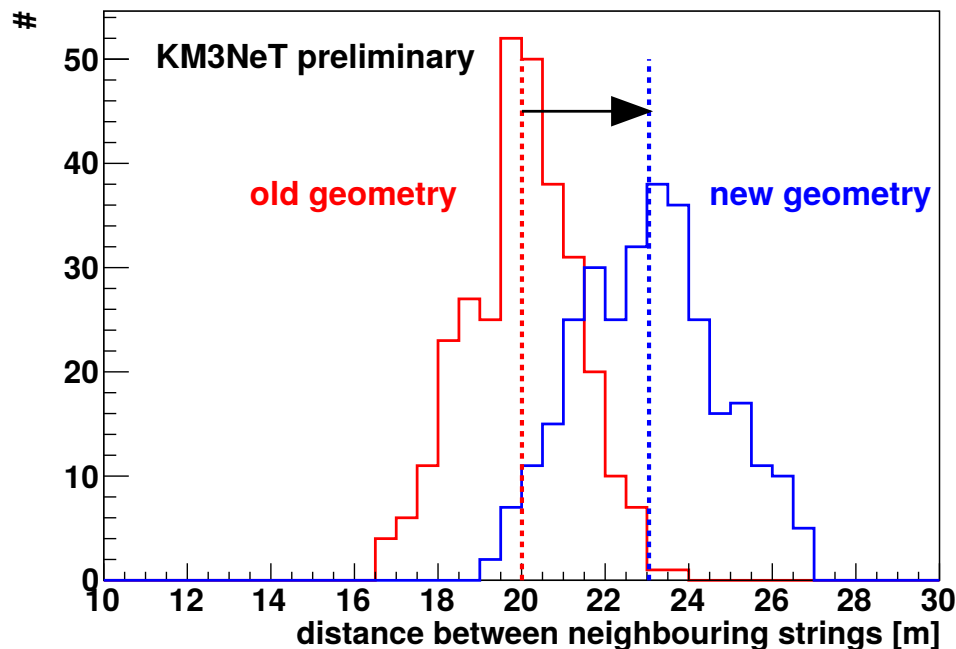
For this study, the masked 9 m simulation used for the Letter of Intent is used.

New ORCA simulations

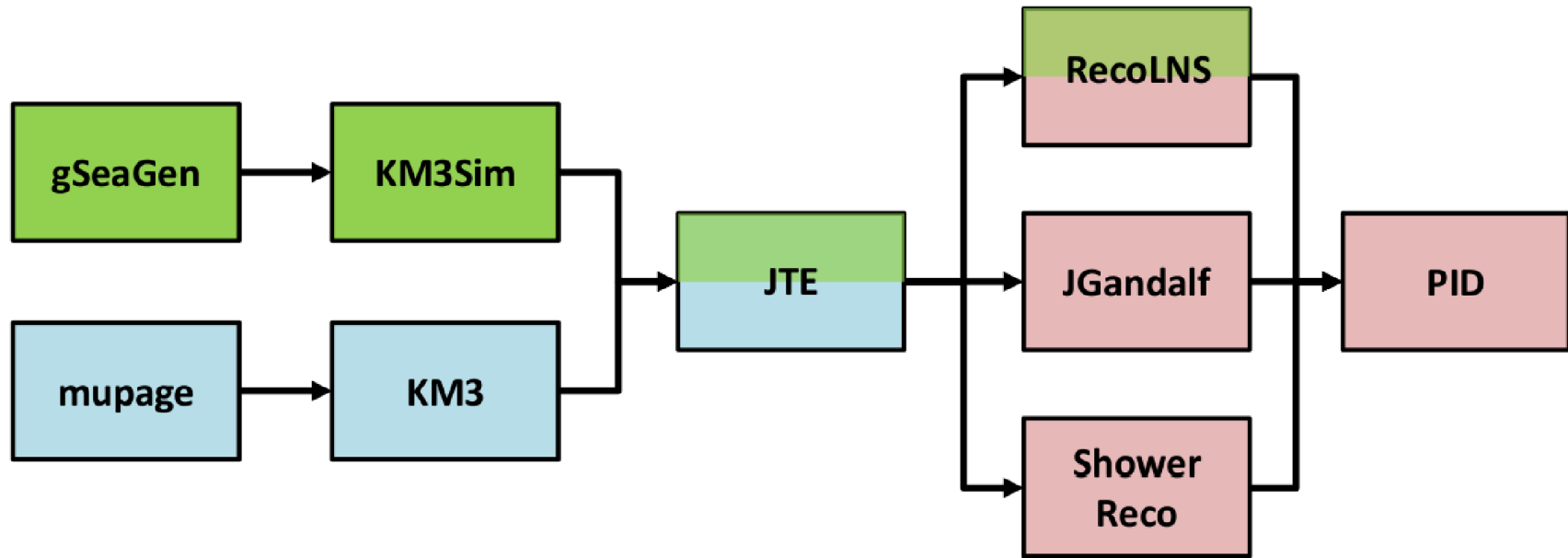


Work on new simulations based on **real detector-layout** in progress:

- Geometry adjusted to deployment requirements
- **horizontal spacing:** average 20 m \rightarrow min. 20 m
- **vertical spacing:** \approx 9m, varying for deployment with LOM (deployment vehicle)
 \rightarrow validated in test deployments ✓



New ORCA simulations



- **gSeaGen + KM3Sim (Interaction, light & hit generation)** ✓ done
- **JTriggerEfficiency (Addition of noise, triggering)** ✓ done
→ 51 Hz atm. μ , 10 (20) Hz random noise from track (shower) trigger
- **Reconstructions** *started*
→ Comparison of **track resolution** of the new simulation showed **no deterioration compared to 'Letter of Intent' simulation**
- **Event classification (= Particle ID)**
pending + work on new classification started

Sensitivity of the KM3NeT/ORCA detector to tau-neutrino appearance



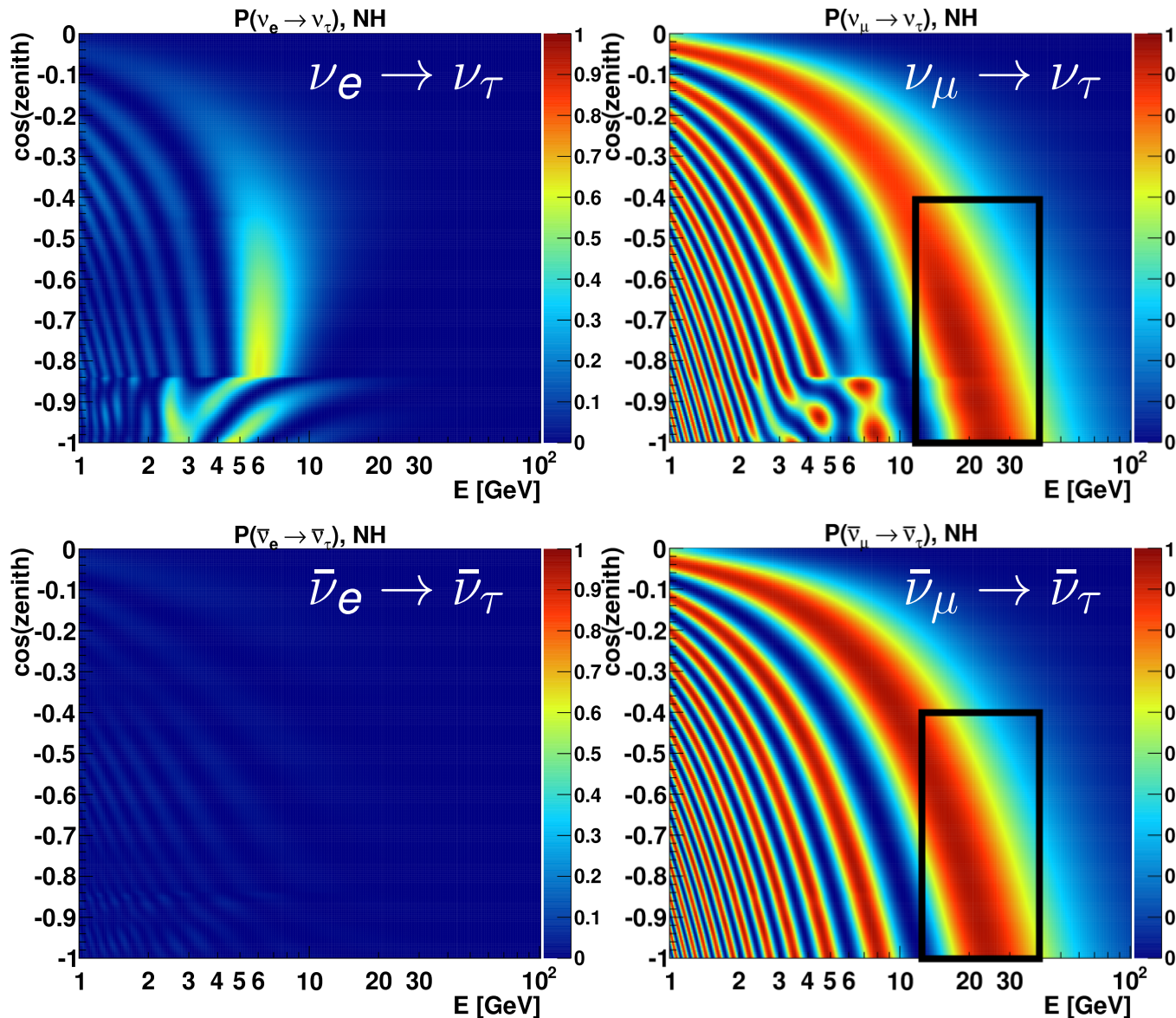
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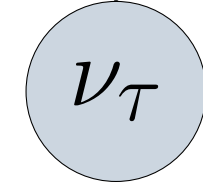
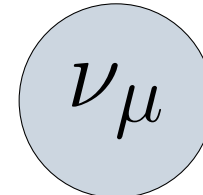
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Oscillation of atmospheric ν_e, ν_μ to ν_τ



disappearance



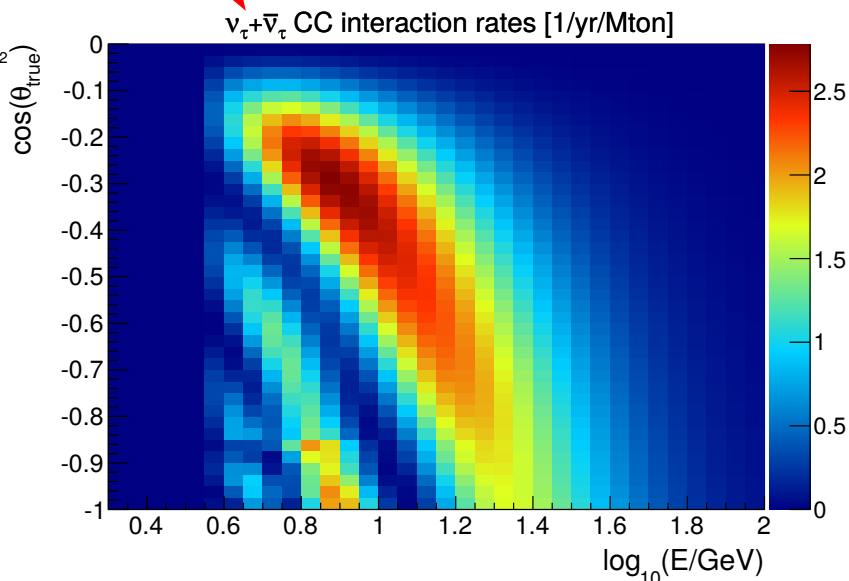
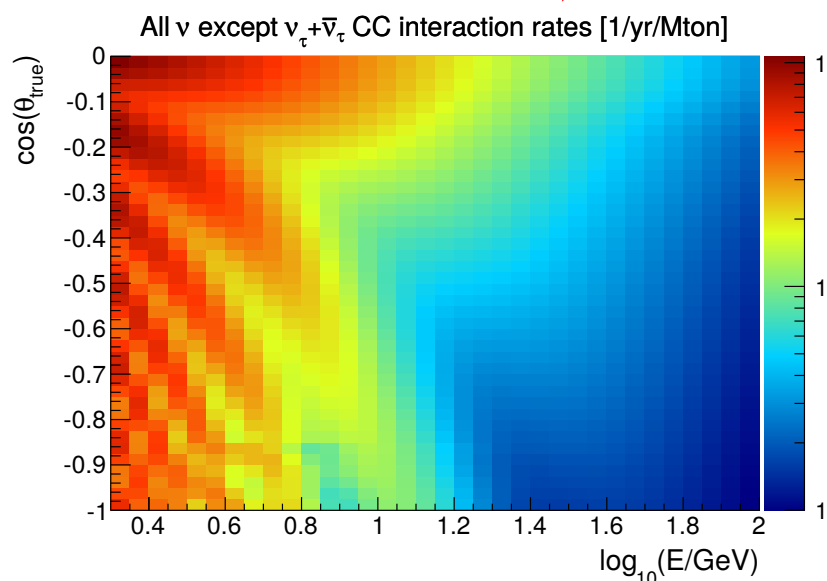
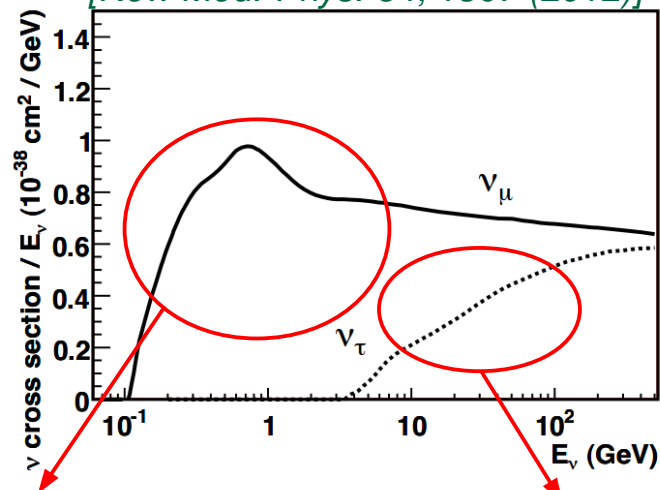
appearance

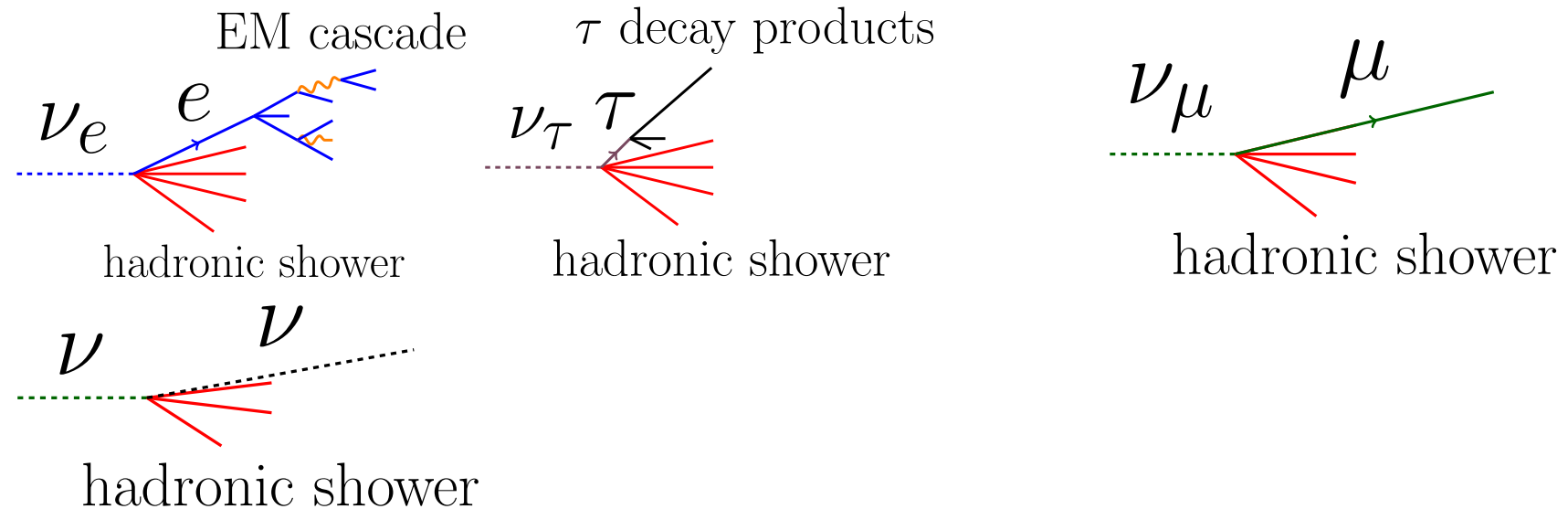
Interaction rates



ν_τ -channel suppressed due to smaller cross-section at relevant energies

[Rev. Mod. Phys. 84, 1307 (2012)]





τ lepton is very short-lived:

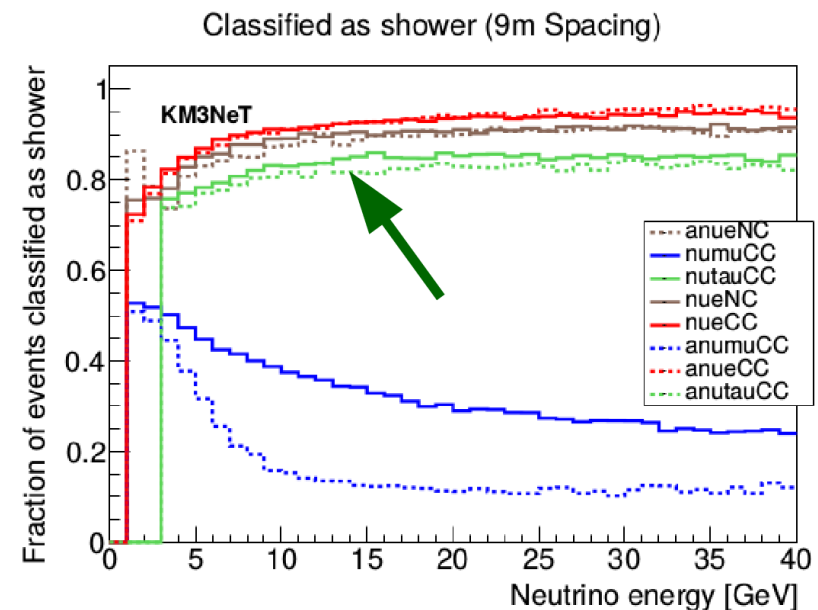
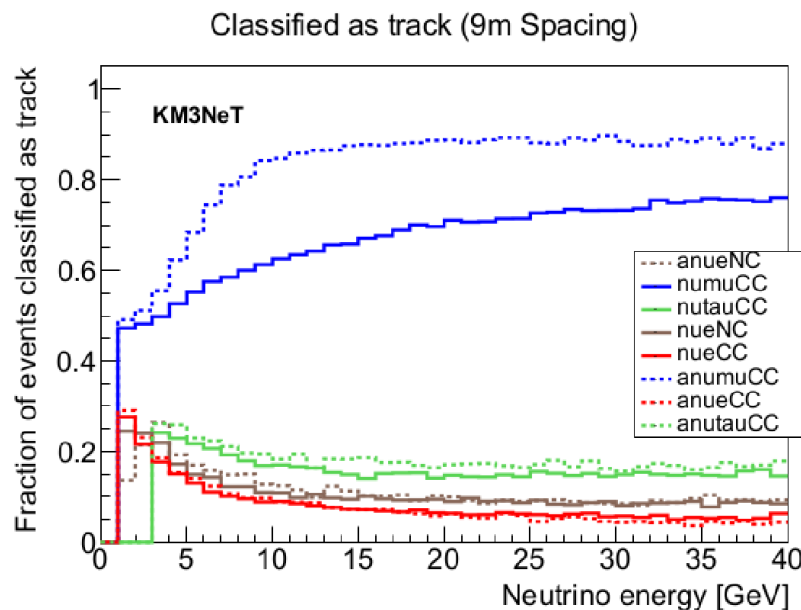
- travel length $\sim 50 \mu\text{m} \times E_\tau [\text{GeV}]$ τ -track unresolvably short
- 17.4%: $\tau \rightarrow \mu \nu_\mu \nu_\tau$ TRACK! (at least potentially...)
- **82.6%: SHOWERS!**

Reconstructed events in ORCA



Interaction \rightarrow detected events \rightarrow reconstructed events

- **Account for reconstruction using smearing tables:**
 $\text{angle} (E_{true}, \cos(z)_{true} \rightarrow \cos(z)_{smeared}) + \text{energy} (E_{true} \rightarrow E_{smeared})$
- **Classification of events using Random Decision Forest:**
 3 event classes: track \leftrightarrow shower \leftrightarrow atmospheric μ



[*J. Phys. G*, 43 (8), 084001, 2016]

\rightarrow 85% of ν_τ identified as shower above ~ 15 GeV

\leftrightarrow No special class/features tailored to ν_τ analyses are used

Event rate: reconstructed+classified



- consider all up-going events classified as shower-like:

Signal: ν_τ CC **2450 events/year**

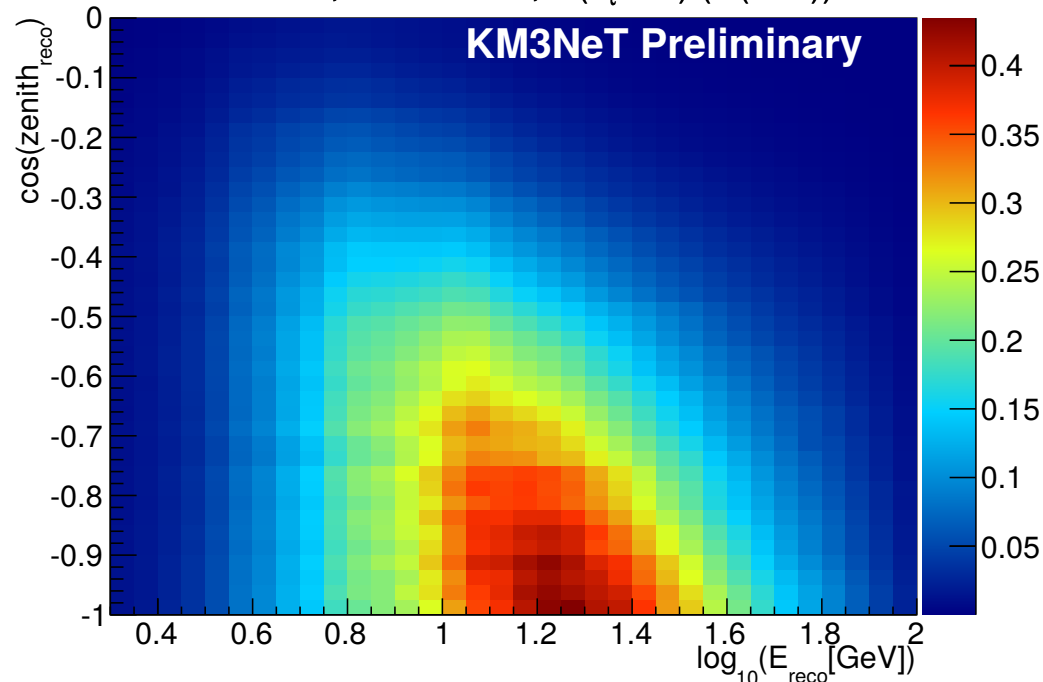
→ up-going and centered around 6–20 GeV

Background: ν_e CC, ν_μ CC, ν NC **17 k, 11 k, 6 k events/year**

→ bulk below 10 GeV

Per-bin statistical significance:

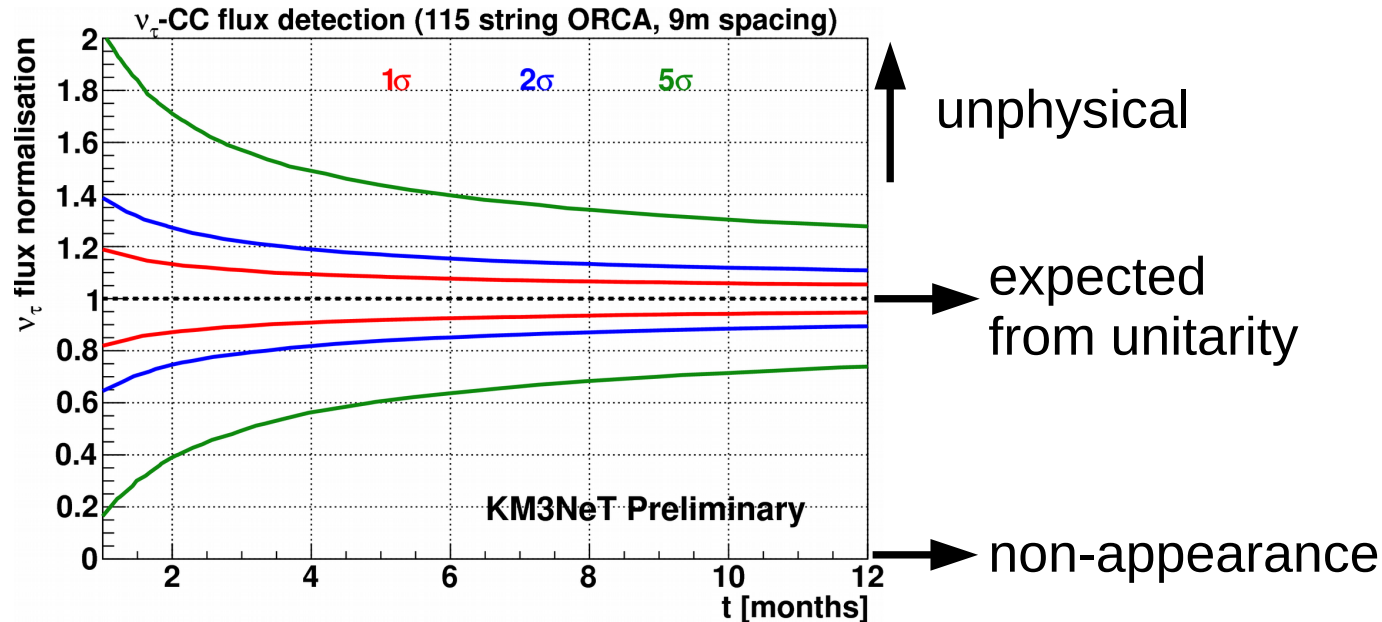
1 month, shower-like, $N(\nu_\tau \text{ CC}) / (N(\text{all } \nu))^{0.5}$



Sensitivity to ν_τ -appearance



- Calculation using log-likelihood-ratio (flux with $\alpha \times \tau$ vs. flux with $1 \times \tau$)

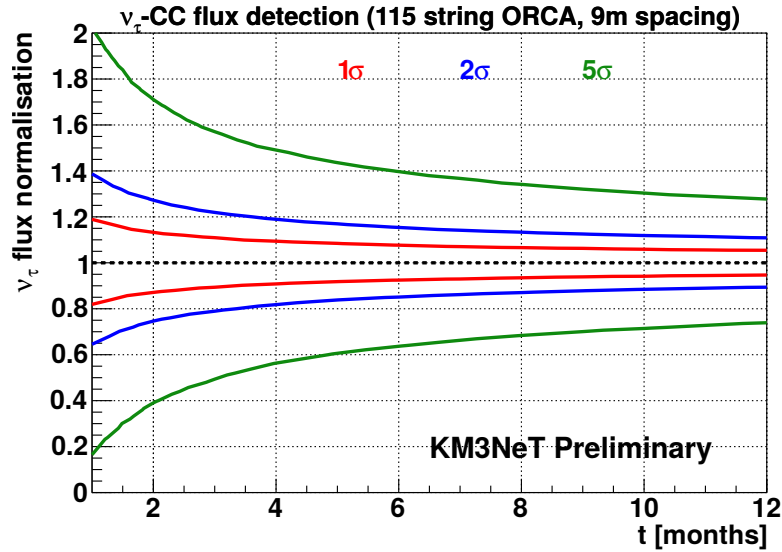


- Systematic uncertainties (flux, cross-section, oscillation, etc.)
not yet taken into account
- Analysis based on energy and direction of shower-classified events:
gain from cuts and additional features?

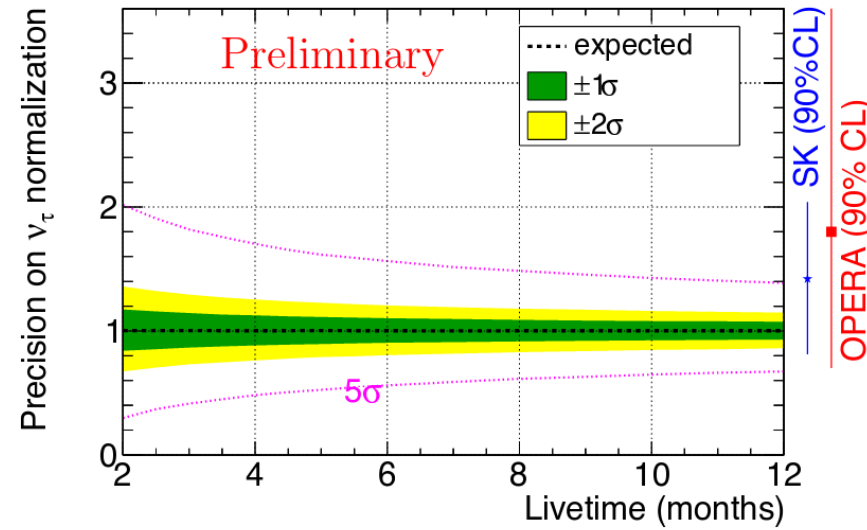
Comparison with IceCube



ORCA, preliminary

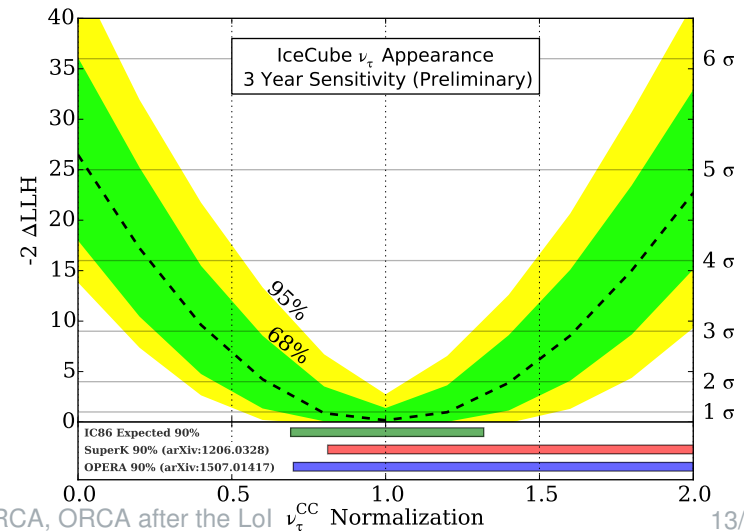


Pingu [arXiv:1607.02671]



DeepCore

[M. Larson, Poster at Neutrino2016]



ν_τ s in KM3NeT/ORCA Phase 1?



- KM3NeT/ORCA Phase 1 will host 7 detection units (=strings)
- high sensitivity to exclude non-appearance with full ORCA
→ study of ν_τ appearance with partial array started
- surface detector → atm. muon suppression more critical



Other studies after the Mass Hierarchy focussed Letter of Intent



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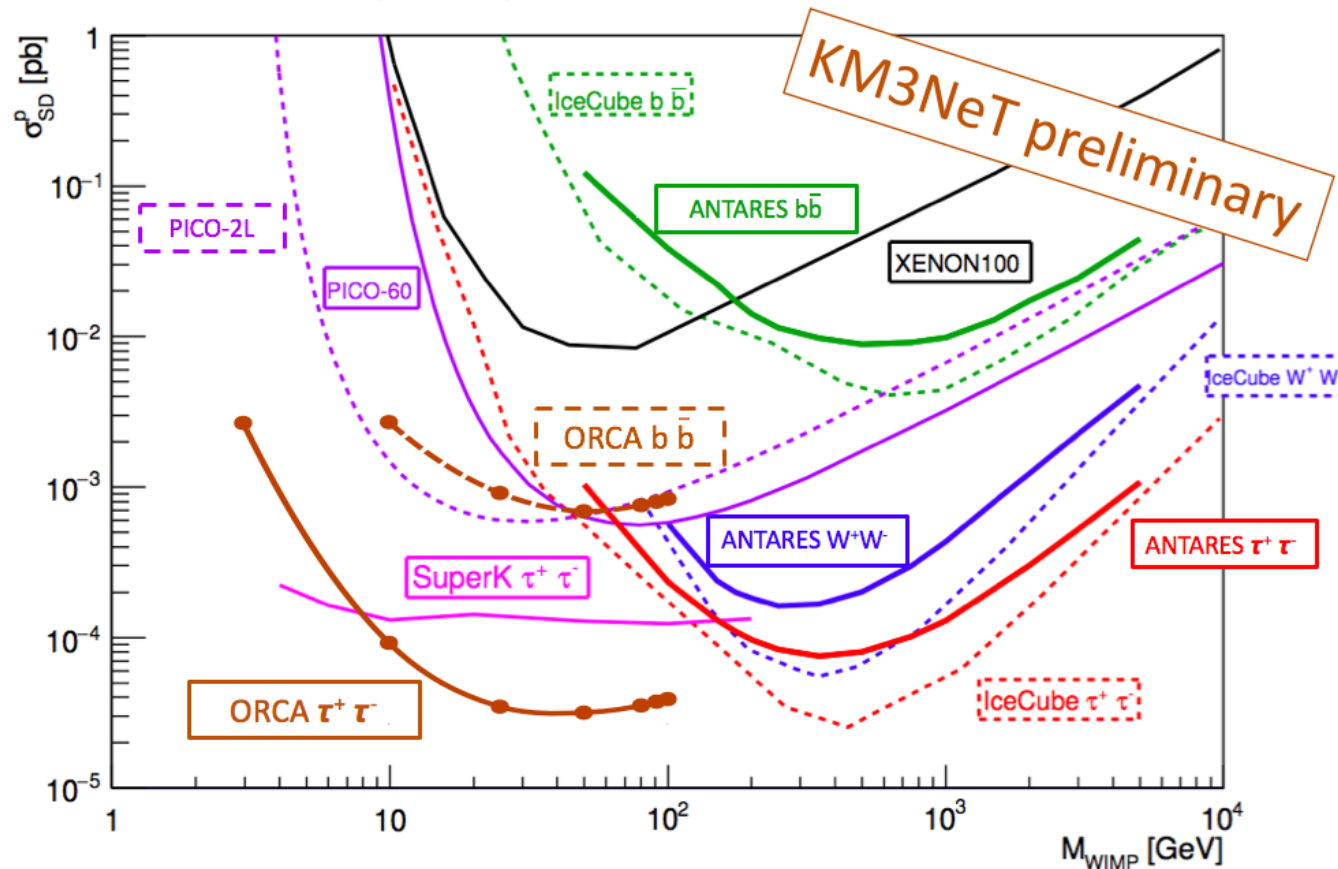


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ORCA sensitivity – 3 years

work by V. Kulikovskiy, Neutrino2016



- ORCA has is most sensitive for **spin-dependent** cross sections in the energy range from **10 to 100 GeV**

Chemical composition of the Earth (1)

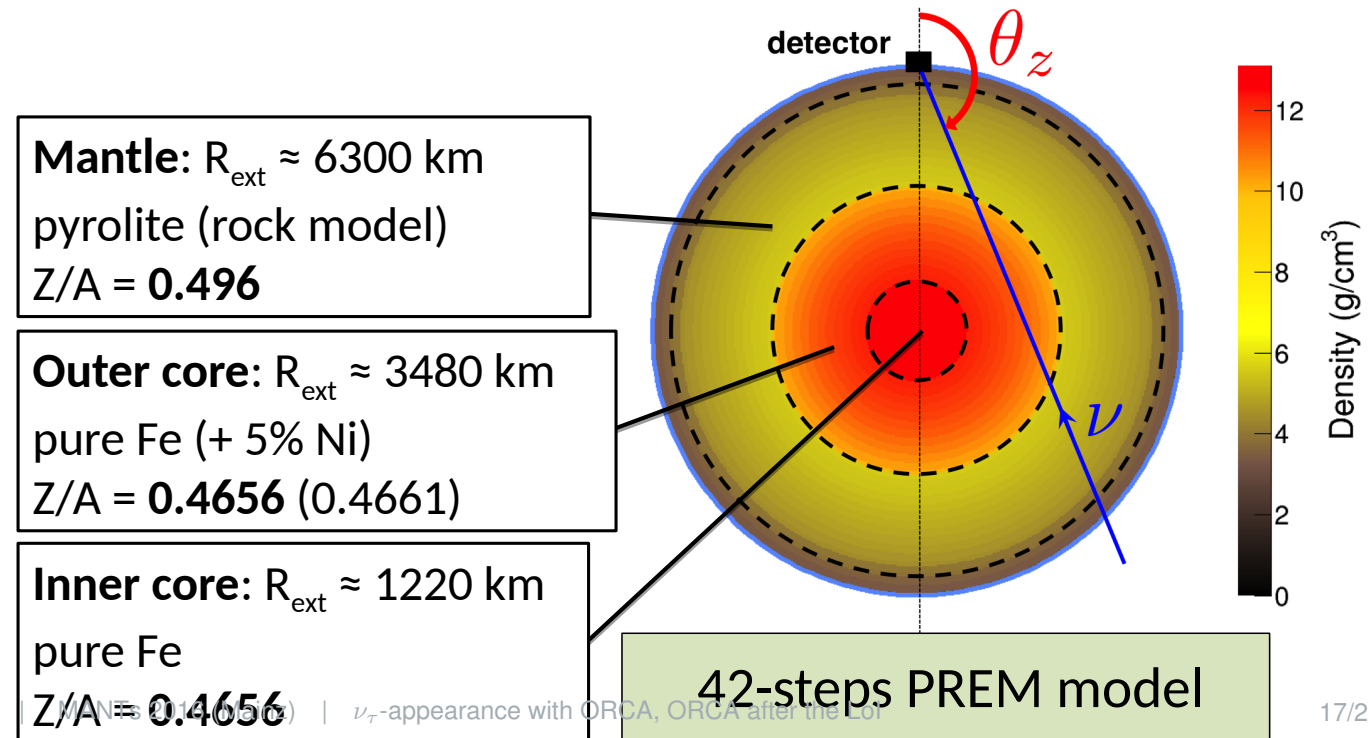


Basic Earth density model assumed: *work by S. Bourret, Neutrino2016*

- General idea: use PREM model as a basis

[Physics of the Earth and Planetary Interiors. 25 (4): 297–356 (1981)]

- introduce Z/A rescaling
- **3 chemically distinct layers**
- **Z/A uniform inside each layer**



Chemical composition of the Earth (2)

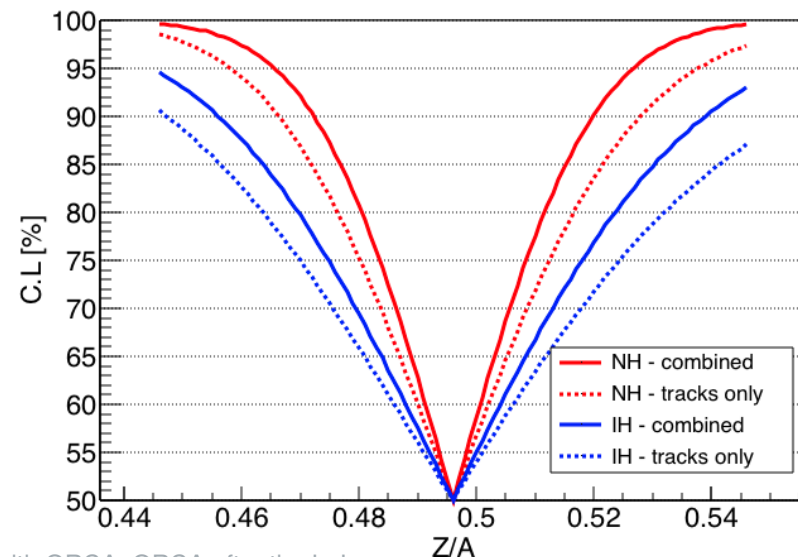
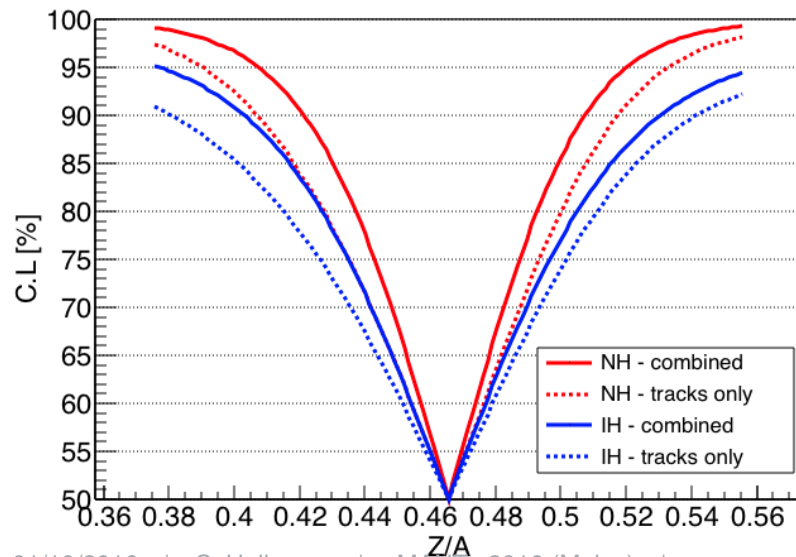


Proportionality factor between **electron density** and **matter density** depends on chemical & isotopic composition (w_i = weight fraction):

$$\frac{Z}{A} = \sum_i w_i \frac{Z_i}{A_i} \longrightarrow n_e = \frac{N_A}{m_n} \times \frac{Z}{A} \times \rho_{matter}$$

Confidence level of rejecting basic composition vs. alternative True Z/A in the ...

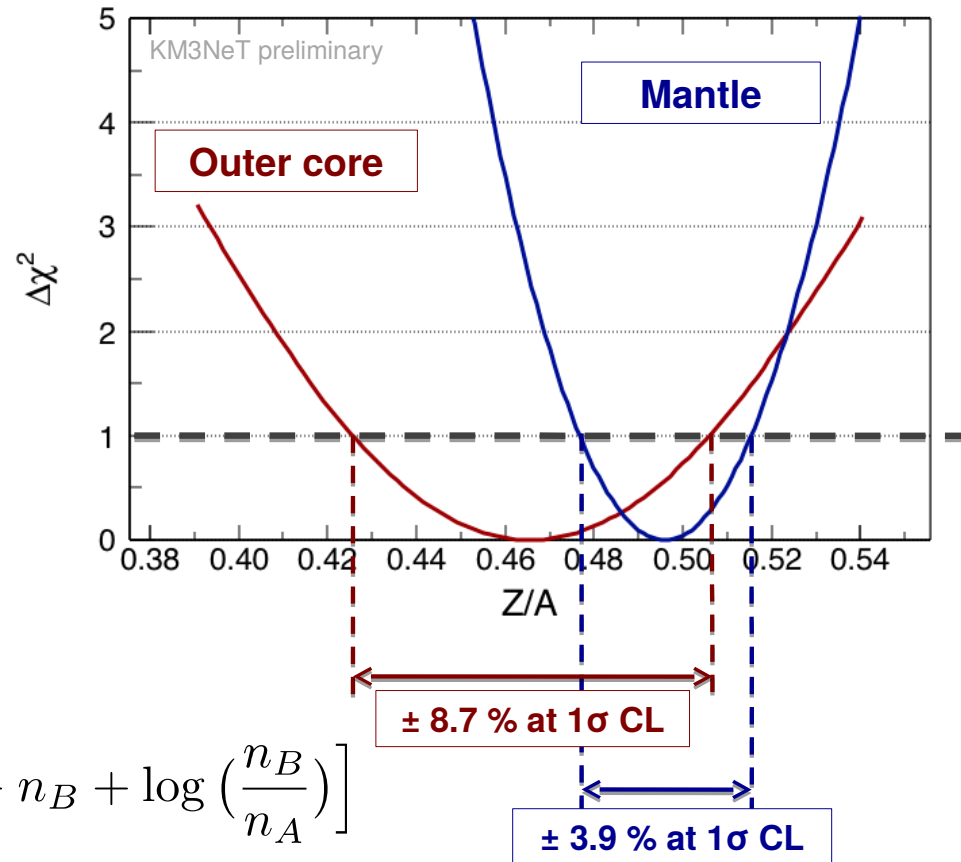
outer core
(pure Fe)
mantle
(pyrolite)



Chemical composition of the Earth (3)



Statistical significance ORCA, 10 years livetime



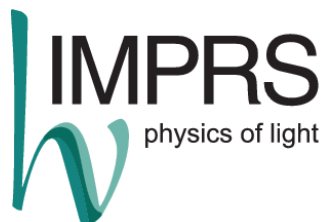
$$\Delta\chi^2 = \sum_{\substack{\text{Tracks,} \\ \text{Cascades}}} \sum_{\substack{\text{bins } E \\ \text{bins } \cos\theta_z}} 2 \left[n_A - n_B + \log \left(\frac{n_B}{n_A} \right) \right]$$

Summary, future plans



- ORCA and Pingu have unprecedented sensitivity to ν_τ appearance
- Sensitivity with full ORCA:
 - exclusion of non-appearance within ≈ 1 month
 - stringent limits ($\sim \pm 20\%$ after 1 year @ 3σ)
 - caveat: flux/oscillation/Xsection parameters still fixed at true value
- Full ORCA \rightarrow KM3NeT Phase 1 ORCA:
 - Study just started
- Broader spectrum of physics topics being investigated since the Letter of Intent is published (e.g. Dark Matter, Chemical Composition)
 \rightarrow see also subsequent talk by João Cohelo
- Big leap ahead: Simulations with **real detector** layout on-going

Thank you for your attention!



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